A watercolor illustration of the NASA Marshall Space Flight Center. On the left, a large, multi-story building is depicted with an American flag and a circular emblem. In the background, the Space Shuttle Challenger is shown on the launch pad. The scene is reflected in a body of water in the foreground. The text is overlaid on the upper right portion of the illustration.

# A Case Study on the Failure on Apollo 13

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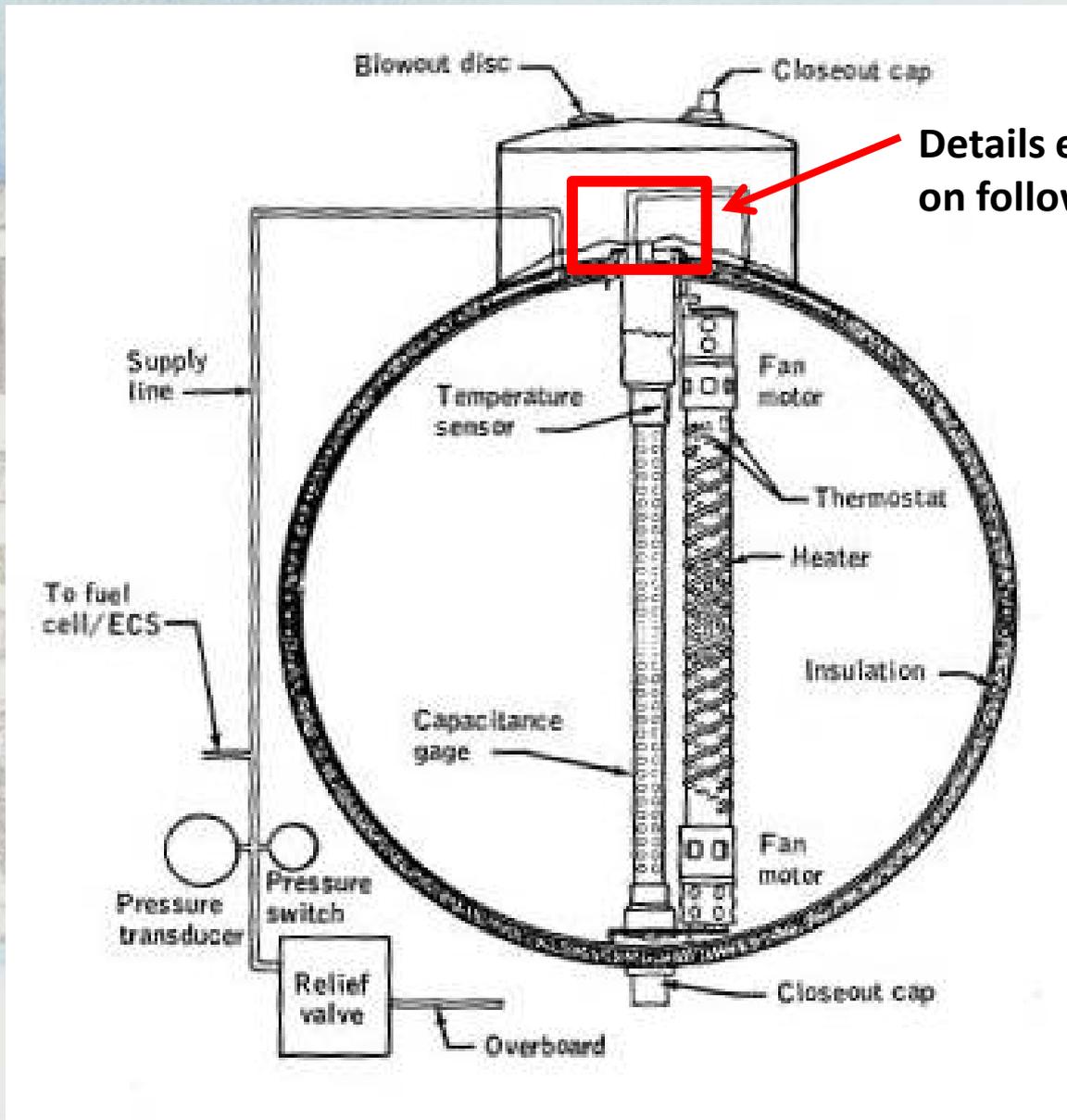
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# Failure on Apollo 13

- At 46:40:02 Mission Elapsed Time during the Apollo 13 mission, both oxygen tank fans were powered on, hopefully to get a more accurate reading of the tank pressure. Tank #1 had performed without anomaly in testing but began to show odd readings after the mission commenced. Tank #2 had multiple issues since manufacture.
- Extended use of the heaters on O2 #2 had, in an effort to empty the tank in testing had, apparently, melted the Teflon insulation. However, what caused the tank difficulty such that it would not empty normally, as such tanks had previously?

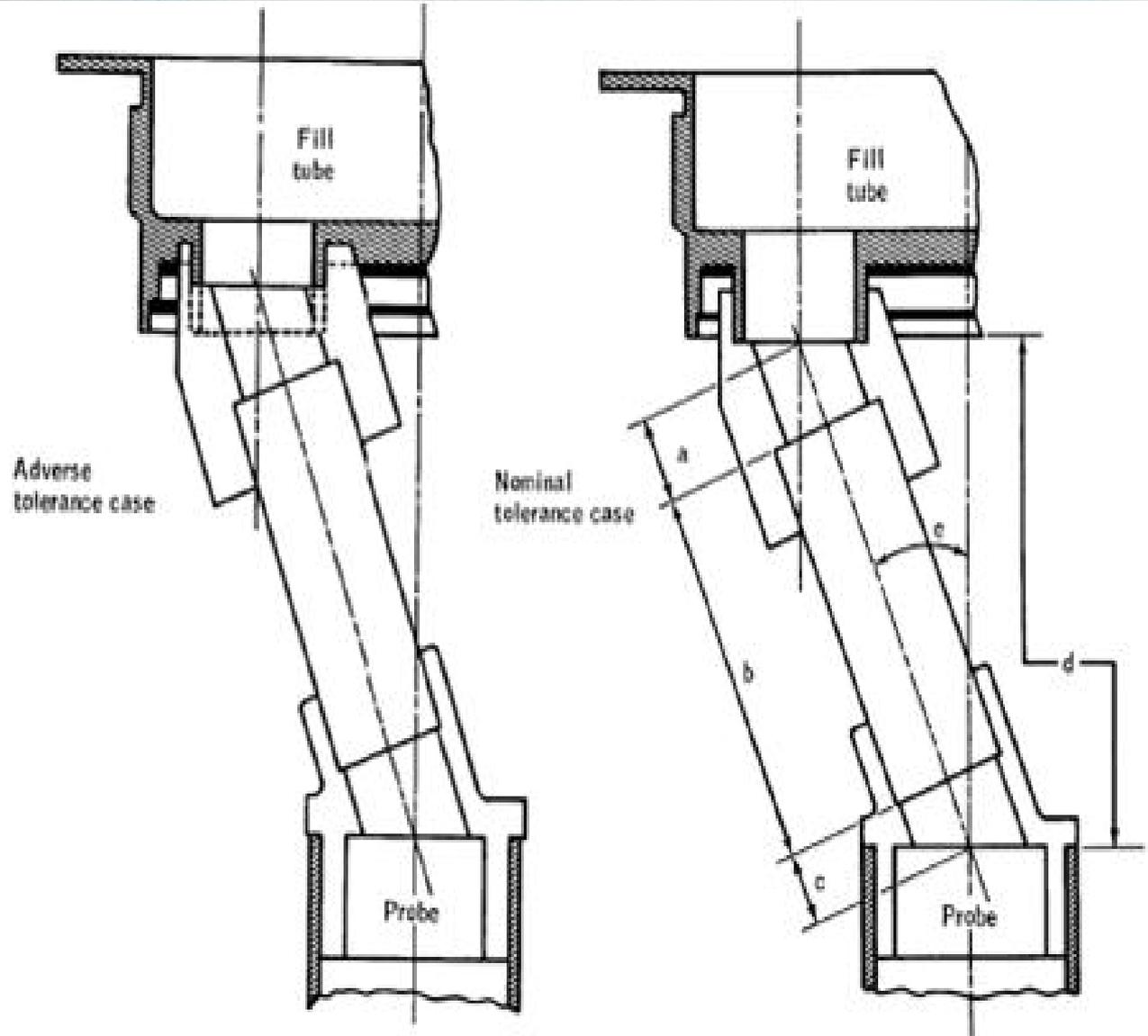
# Apollo Oxygen Tank Assembly



Details expanded on following chart

# Nominal and Adverse Coupling Tolerances

For worst case deviations, a loose fit is ensured for the coupling



# Manufacturing History Oxygen Tank #2

- Tank #2 was manufactured as two hemispheres and joined. Electrical and fill tubes are inserted. Bolting and wiring occurs through the opening at top.
- Weld porosity was detected and repaired.
- Upper fan motor extracted excessive current and was noisy, leading to replacement.
- Heater assembly tube required replacement, which included new heaters and fans.

# Oxygen Tank #2 Testing at Manufacturer

- Acceptance testing demonstrated that the heat leak rate into the tank was greater than allowable by specification. The tank was reworked but the leak rate was still high.
- A formal waiver was submitted and accepted for the tank to be used “as is”.

# Assembly and Testing of O2 Tank Shelf

- Oxygen tank #2 was added to the shelf which secures both O2 tanks in the Service Module (SM). No anomalies noted in testing.
- Electromagnetic interference had been recorded on earlier Apollo spacecraft, caused by the O2 tank vacuum ion pump. A design modification eliminated the anomaly. The pumps were to be replaced on this O2 tank shelf.



# Lift Incident

- The tank shelf was disconnected from the SM and the crane placed under it to lift it from position. By mistake one bolt had been left in. The crane lifted approximately two feet, and then broke, dropping the shelf back into position.
- External photos were taken and calculations were performed to estimate the force from the fall. After the vacuum ion pump was replaced, no further anomalies were noted and no other work performed on the O2 tank.

# O2 Tank Testing at KSC

- A countdown demonstration test (CDDT) was performed with no anomalies during tank filling. However, O2 tank #2 would not empty. The CDDT was completed and then dialogue conducted concerning the tank.
- The decision was that there was a leak in the line between the quantity probe and fill line in the tank because of the loose fit between tube and sleeve. A leak would allow gox to leak into the fill line, not driving lox from the tank. A discrepancy report was written.

# O2 Tank Testing at KSC...contd.

- Heating the fill line and using higher pressure O2 did not empty the tank post-CDDT.
- It was decided to use the tank heaters to boil out the lox. They were connected to GSE power supply of 65 V dc rather than the usual operating supply of 28 V dc from the SM. The fans were also turned on to help drive out the oxygen.
- After eight hours of operation, the heaters and fans were turned off and the tank was empty.

# Pre-launch discussion of O2 tank

- KSC personnel were certain that the loose fitting was the reason for O2 tank not emptying. They decided to see if the tank would fill now without problem.
- If the tube was loose, it could cause a short in flight but not generate enough heat to cause a problem. This would be the flight rationale. Tank #2 again required pressure cycling and heating to empty.
- The pre-launch discussions focused on the loose fitting and did not address the extended operation of the heaters and fans or the drop during re-work. Most individuals in the discussions knew little about the history of the tank, except for the emptying difficulty.

# Pre-launch discussion of O2 tank...contd.

- The heater has a thermostatic switch as protection against extreme heat. The switch should open at 80<sup>o</sup> F. Switches of this type were tested post-failure, and failed to open when the heaters were operated at GSE power of 65 V dc. The switches were rated at 28 V dc, standard operating power for the SM.
- Data recorded during CDDT was reviewed in post-failure investigation and showed that the heater switches did not open during the extended heater operation post-CDDT. Further testing demonstrated that the temperature could have reached a high of 1000<sup>o</sup> F inside the O2 tank, which was shown to cause severe damage to the Teflon insulation on the wiring inside the tank.
- The decision makers did not have any of this information available during pre-launch discussions.

# Summary of Findings

- The post-failure investigation determined that extended operation of the heater damaged the wiring inside O2 #2.
- Apparently during other stir operations prior to the explosion, the damaged wires didn't come in contact enough to spark. The right conditions had to be in position to cause the arcing which led to the blast.

# Unanswered Questions

- However, the unanswered question from the failure investigation is: what led to the tank to be in such a condition that it would not empty, thus leading to the extreme heating environment?
- Why did the failure of the heater thermostatic switches go unnoticed, causing the extreme heating environment?
- What caused the high confidence level in a loose fitting sleeve, leading to incomplete history being presented to the decision makers?